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<u>Test Section Conditions for the Tailored Interface Hypersonic Shock Tunnel</u>

Appendix to H.I.C. No.83 1966

by

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Test Section Conditions for the Tailored Interface Hypersonic Shock Tunnel

Appendix to H.I.C. No.83 1966.

Introduction

This report contains calculated conditions expected in the test section of the Sheffield University Shock Tunnel.

The driver gases used are either cold hydrogen or a mixture of hydrogen oxygen and helium ignited behind the primary diaphragm. Cold hydrogen "Tailors" at a primary shock Mach number of 6 and the helium mixture used at about 12. The report therefore deals with the primary shock Mach number ranges from 5 to 9 and from 9 to 14 to cover both these cases.

The air in the stagnation region is expanded to test section Mach numbers of 3,4 or 5 depending on the nozzle attached.

Symbols used

P	=	pressure	T	=	temperature
h	=	enthalpy	a	=	sound speed
u	=	velocity			
Ms	=	primary shock Mach number.			
Mt	=	test section Mach number.			
Subscript T	=	test section values.			
Subscript 5	=	Stagnation region values			

Method of Calculation

Assumptions made

(i) The expansion through the nozzles from state 5 to state T is assumed isentropic when using Mollier data

(ii) Feldman charts for air were used to obtain values of h_5 P_5 T_5.

(iii) The enthalpy in region 5 appears in region T as

$$h_T + \tfrac{1}{2} U_T^{2} = h_5$$

Method

(i) Find values of h_5 P_5 T_5 using the required conditions P_1 T_1 M_s

(ii) From $h_T + \frac{1}{2} U_T^{2} = h_5$

$$h_T = h_5 - \tfrac{1}{2} (Ma)^2 \qquad \ldots\ldots(A)$$

$\therefore$ Assume a value of "a" and substitute this in (A) hence calculate h_T.

(iii) Using P_5T_5 expand isentropicly on a Mollier chart to h_T.

(iv) Check whether the value of "a" assumed equals the value of "a" at h_T.

(v) Repeat the above until the "a" assumed to calculate h_T equals the "a" at h_T on the chart.

When this is so read off values of $h_TP_TT_T$.

Using the above method values of h_TP_T and T_T were obtained for various primary shock Mach numbers using 3 different values of P_1. The primary shock Mach numbers used include the tailoring Mach numbers for hydrogen and hot lhelium as used at Sheffield.

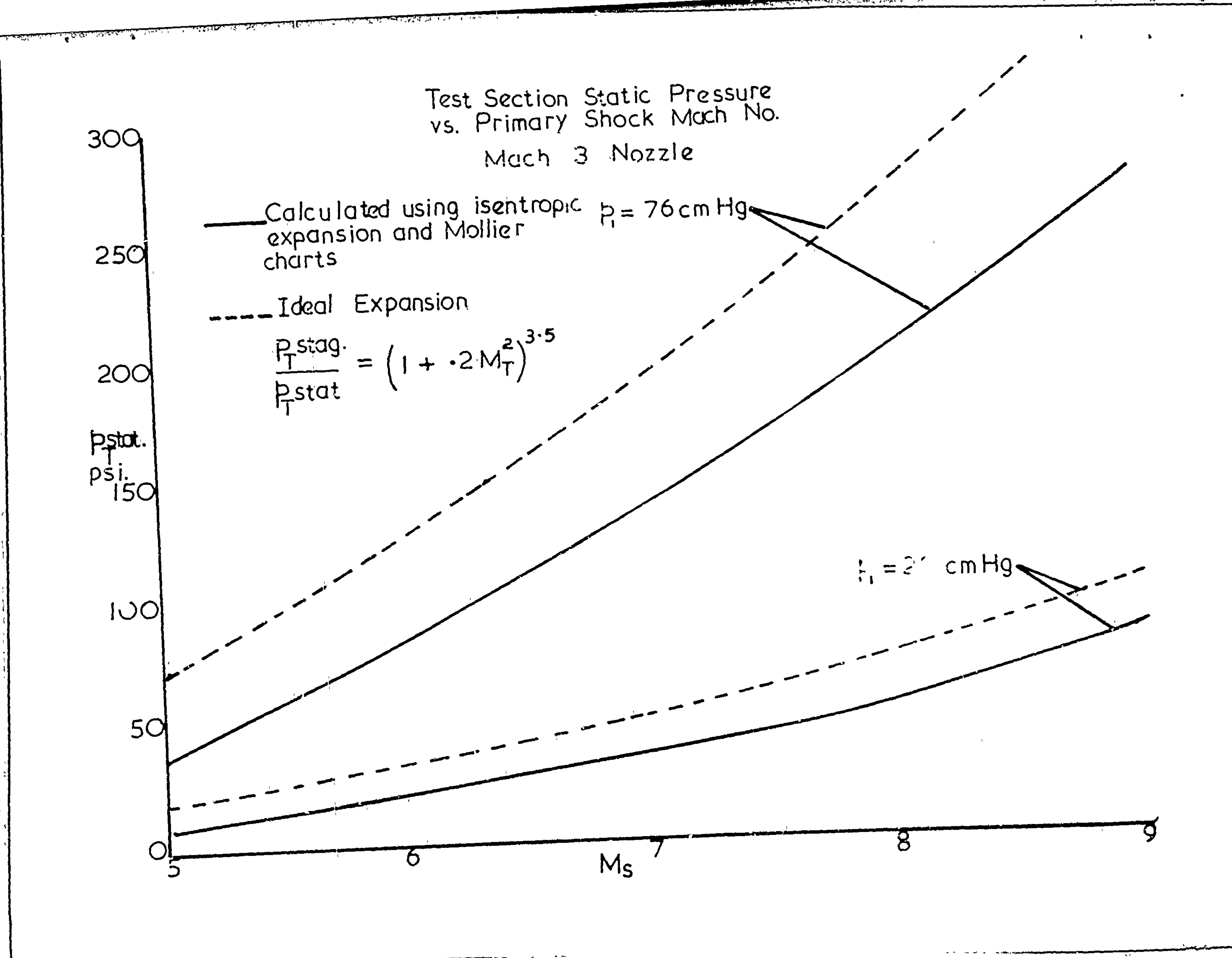
Included on the graphs of P_T and T_T are values calculated assuming ideal gas with $\gamma = 1.4$. Assuming this,

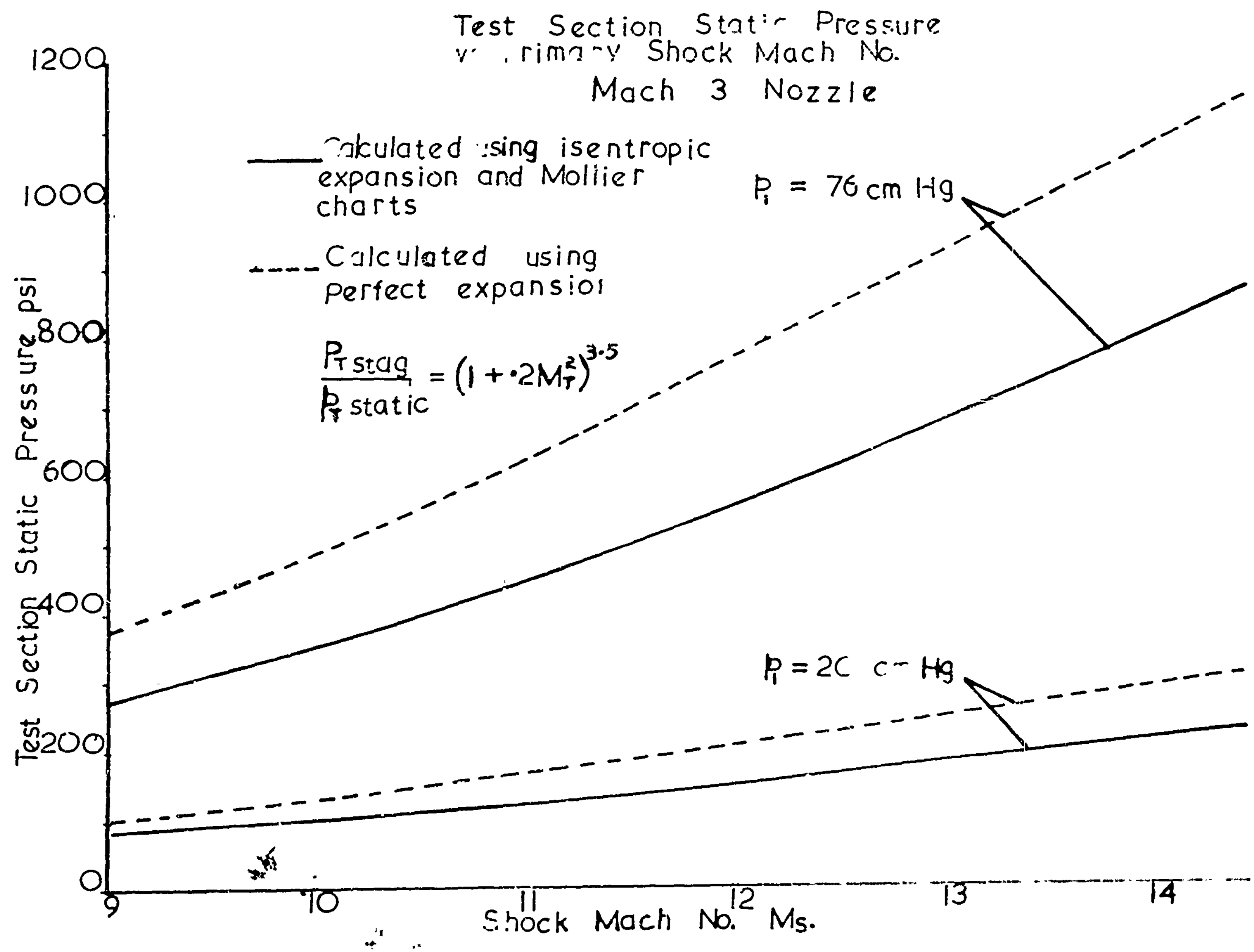
For static temperature $$T_T = \frac{h_5}{RT_o} \frac{1}{3.5(1+0.2M_T^2)} T_o$$

and for static pressure $$P_T = \frac{P_5}{(1+0.2M_T^2)^{3.5}}$$

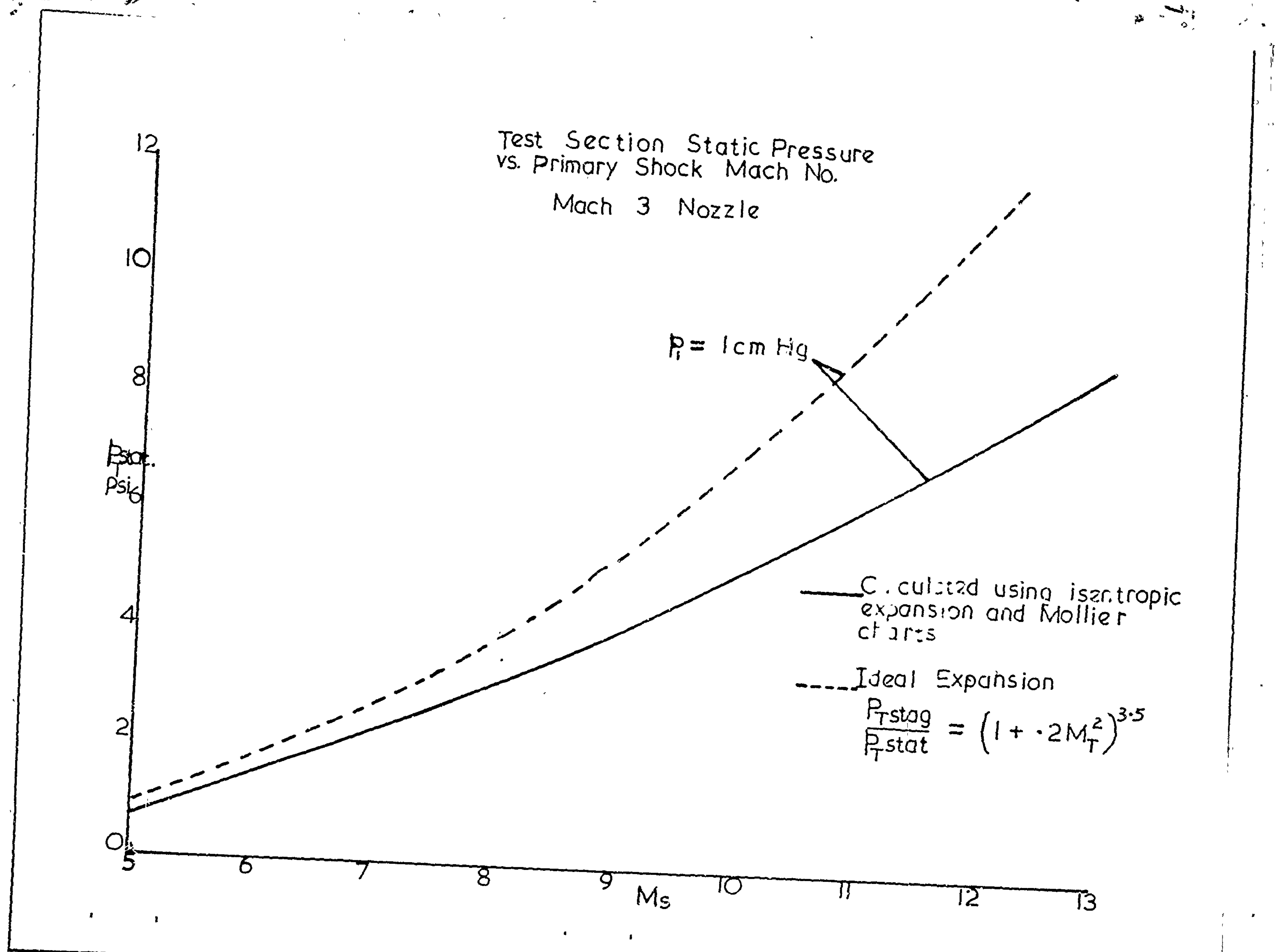
From the graphs it can be seen that these assumptions are only valid at the lower primary shock Mach numbers i.e. when the temperature is less than about 2000°K.

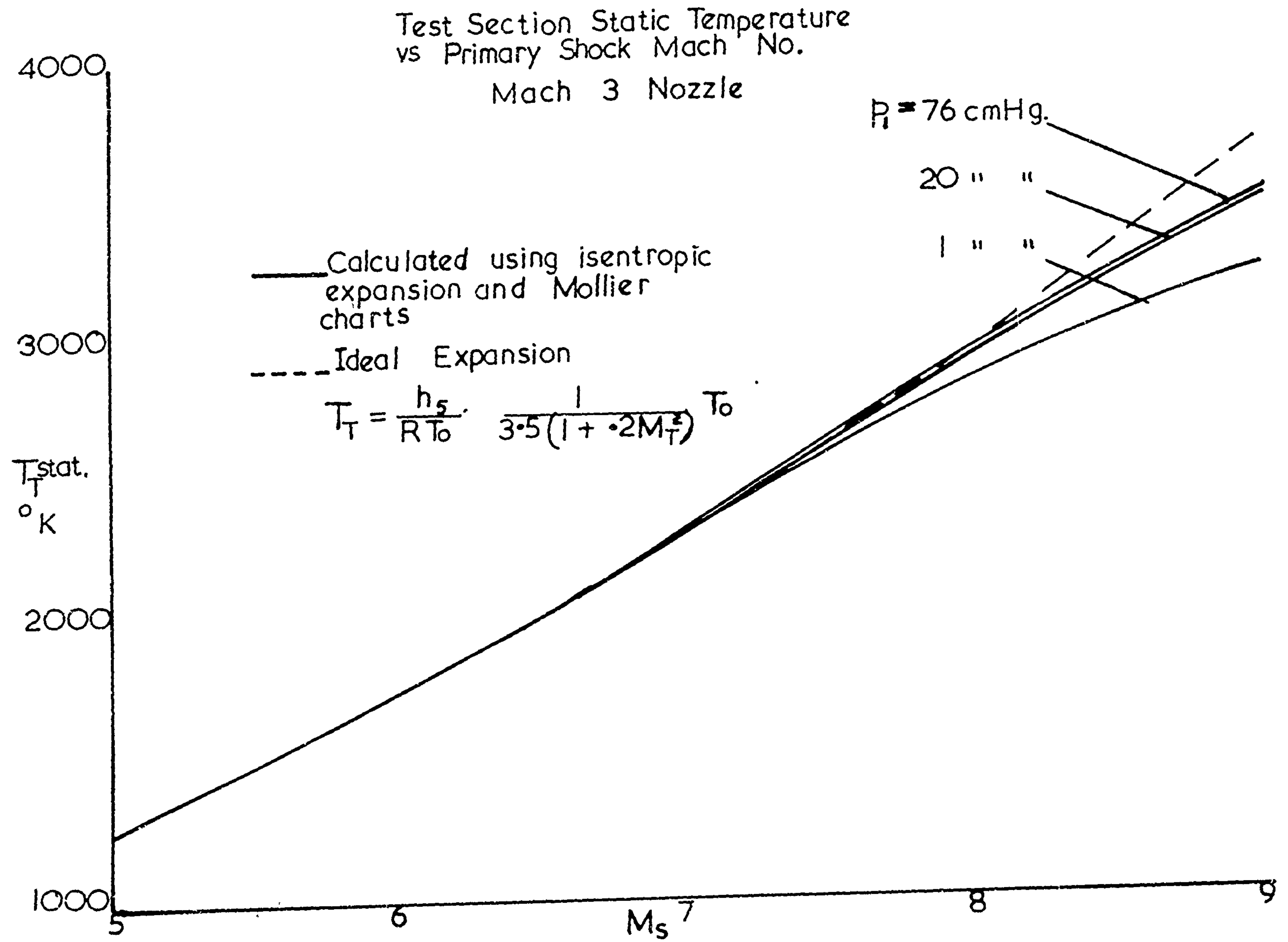
It is proposed to obtain practical values by using static pressure probes and sodium double beam reversal methods.


Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 3 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T stag.}{P_T stat} = \left(1 + \cdot 2 M_T^2\right)^{3\cdot 5}$
p_1 = 76 cm Hg
cm Hg
P_T stat. psi.
300
250
200
150
100
50
0
5
6
7
8
9
M_s

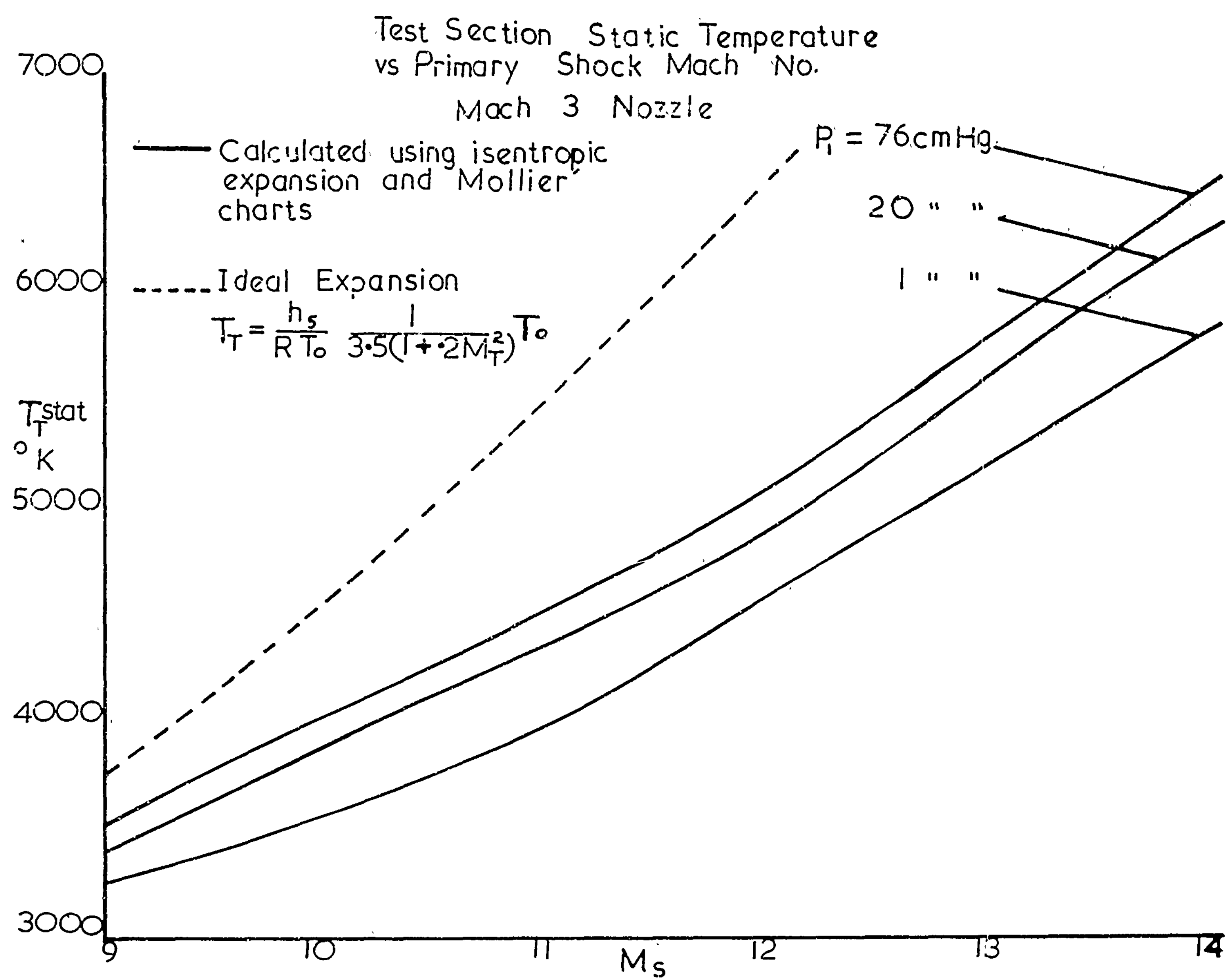


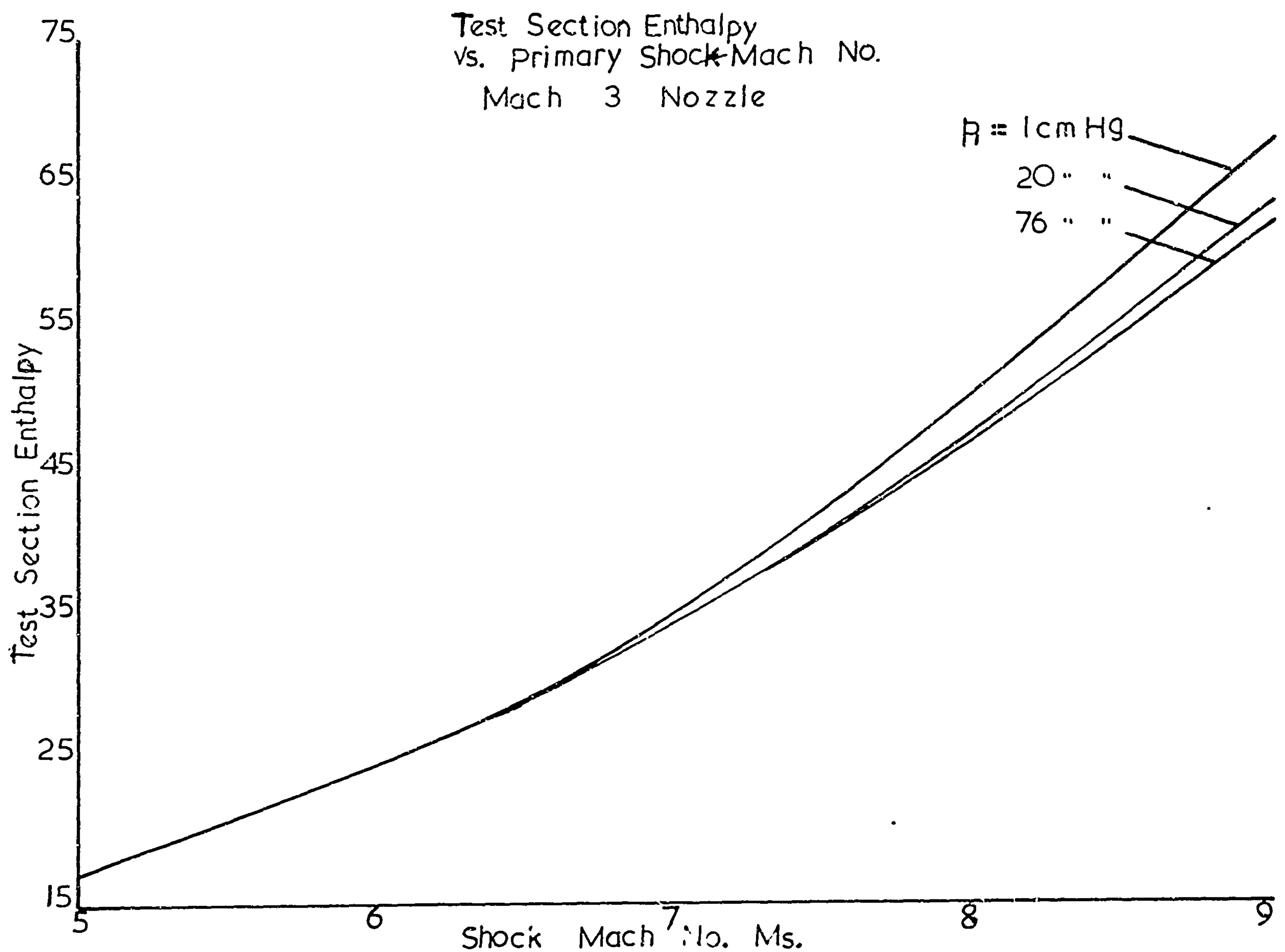
Test Section Static Pressure
vs Primary Shock Mach No.
Mach 3 Nozzle
Calculated using isentropic expansion and Mollier charts
Calculated using perfect expansion
$\frac{P_{T\,stag}}{P_{T\,static}} = (1 + \cdot 2M_T^2)^{3\cdot 5}$
P_1 = 76 cm Hg
P_1 = 20 cm Hg
1200
1000
800
600
400
200
0
Test Section Static Pressure psi
9
10
11
12
13
14
Shock Mach No. Ms.

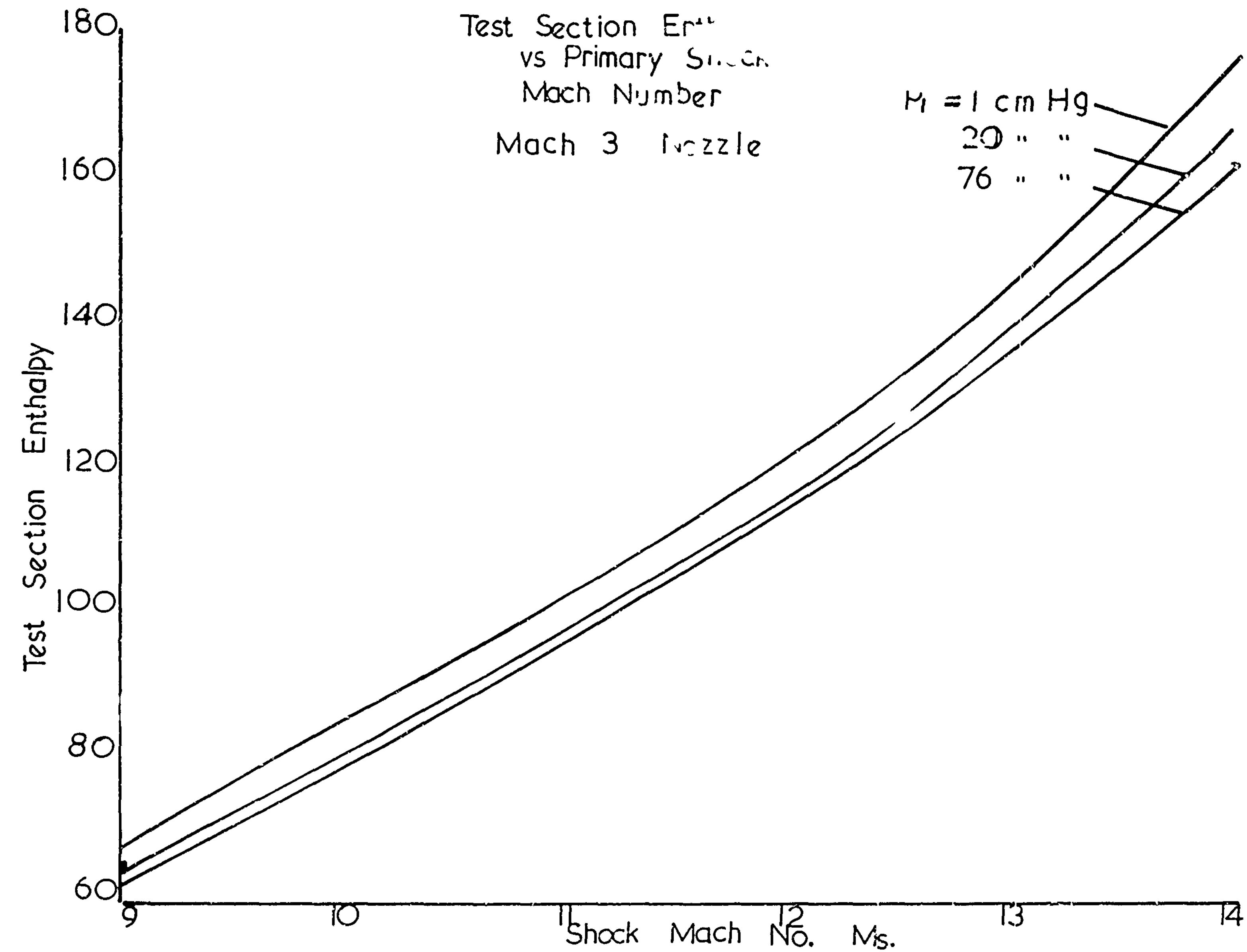

Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 3 Nozzle
P_1 = 1cm Hg
P_{T}stat. psi
0
2
4
6
8
10
12
5
6
7
8
9
10
11
12
13
Ms
C. culated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_{T}stag}{P_{T}stat} = (1 + .2M_T^2)^{3.5}$



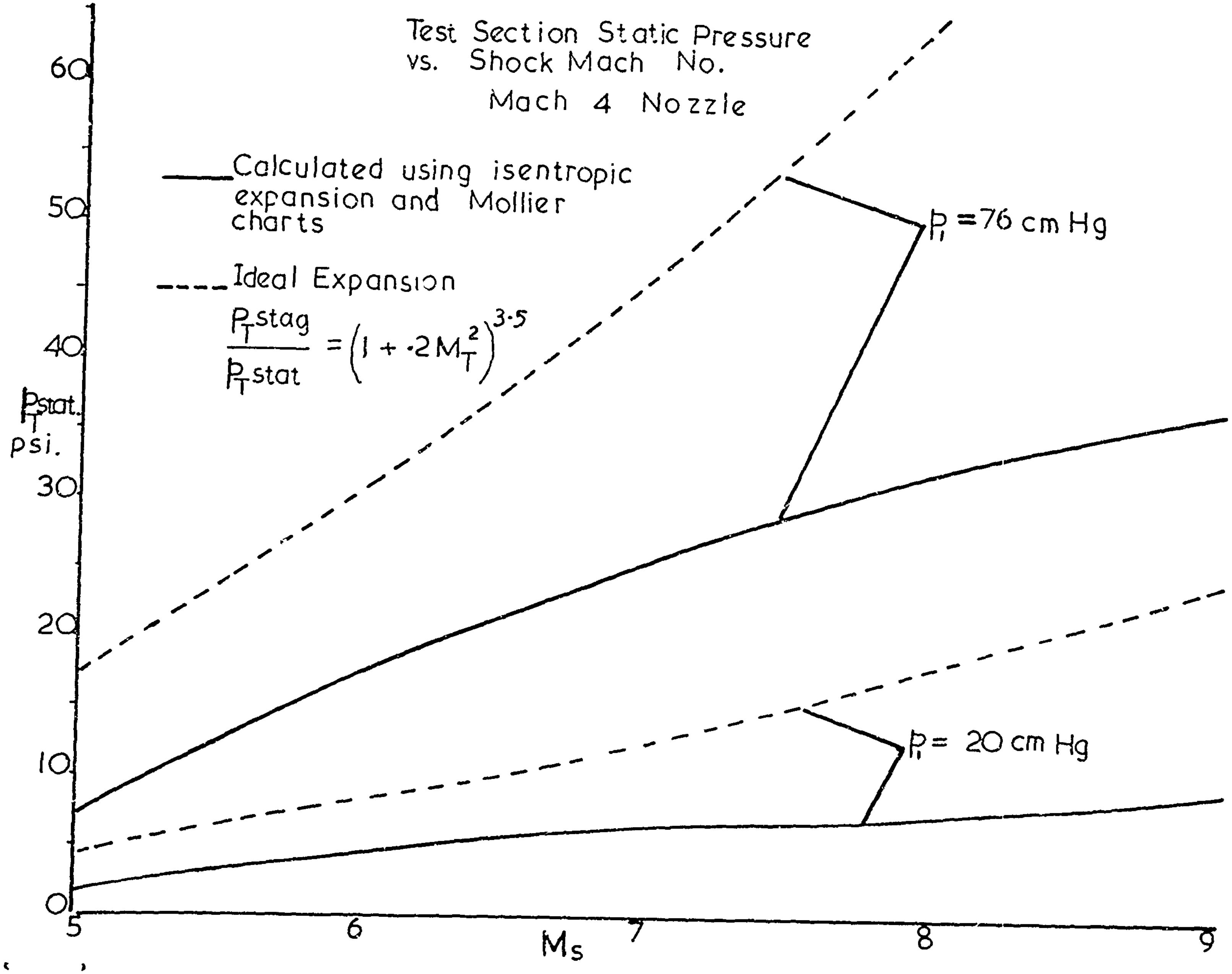
Test Section Static Temperature
vs Primary Shock Mach No.
Mach 3 Nozzle
P_1 = 76 cmHg.
20 " "
1 " "
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{R T_0} \cdot \frac{1}{3{\cdot}5(1 + {\cdot}2M_T^2)} T_0$
$T_T^{stat.}$ °K
4000
3000
2000
1000
5
6
7
8
9
M_s

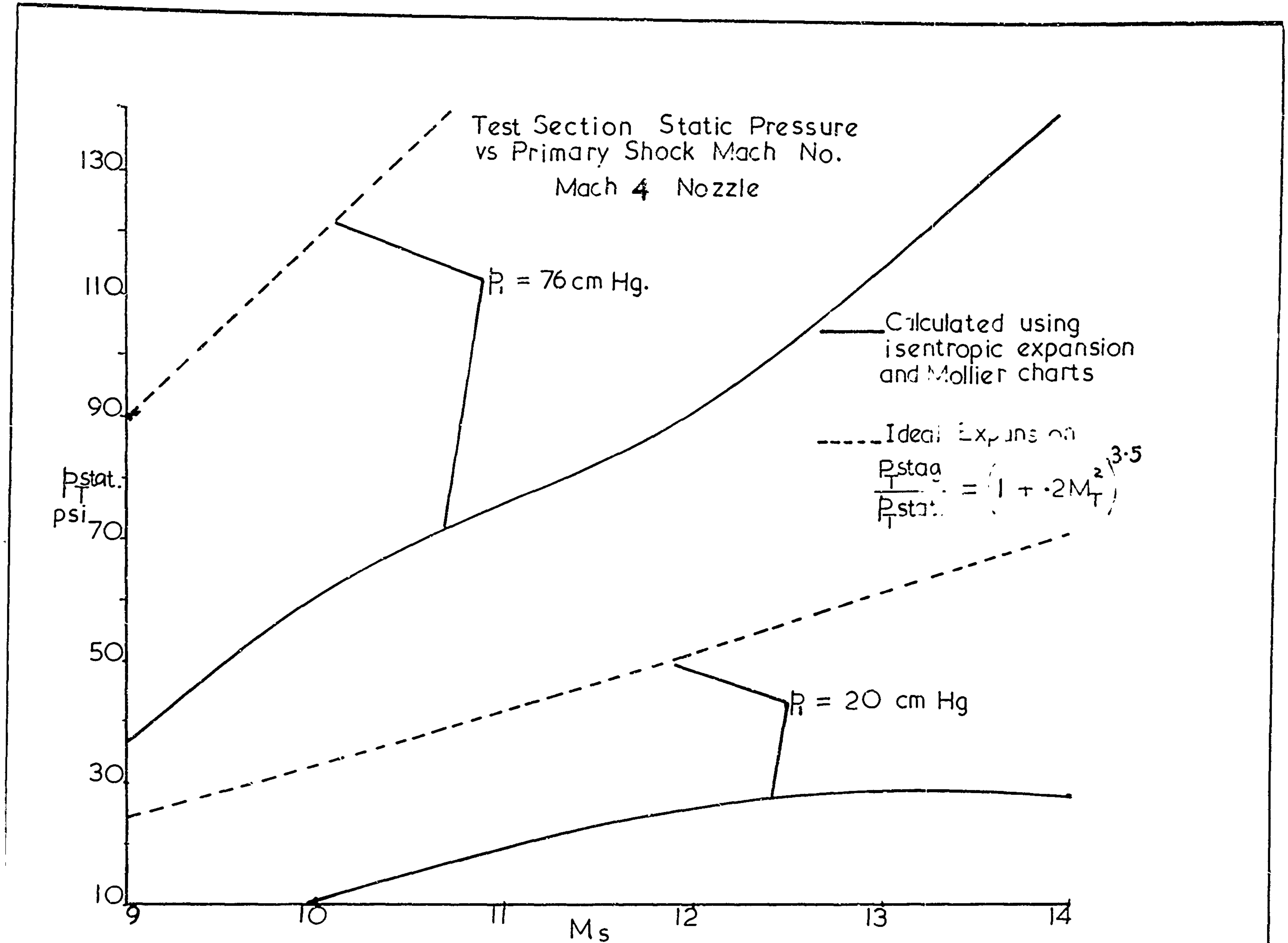

Test Section Static Temperature
vs Primary Shock Mach No.
Mach 3 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{R T_o} \frac{1}{3{\cdot}5(1+{\cdot}2M_T^2)} T_o$
P_1 = 76cmHg
20 " "
1 " "
T_T^{stat} °K
7000
6000
5000
4000
3000
9
10
11
12
13
14
M_s

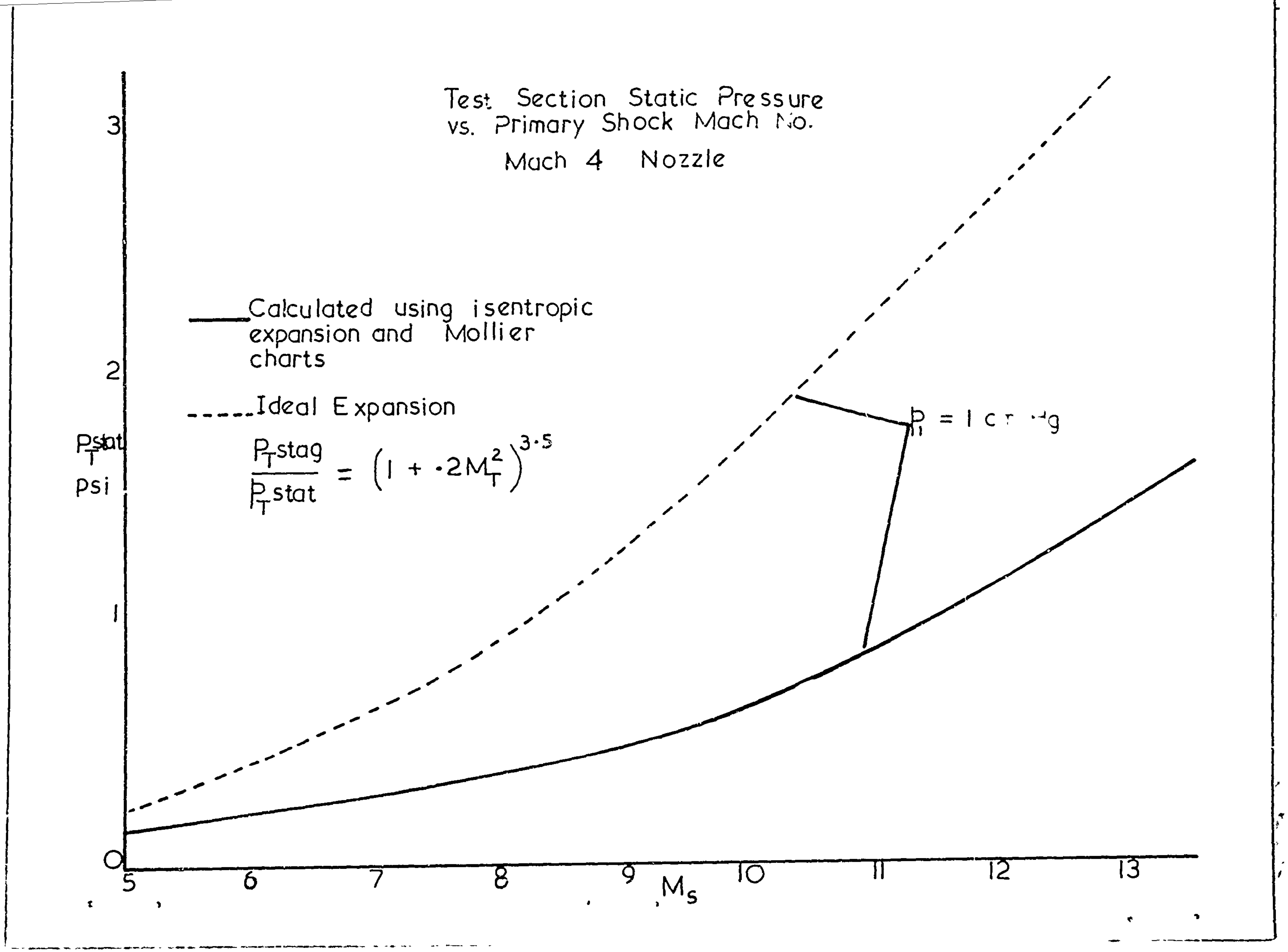

Test Section Enthalpy
vs. Primary Shock Mach No.
Mach 3 Nozzle
P_1 = 1 cm Hg
20 " "
76 " "
75
65
55
45
35
25
15
Test Section Enthalpy
5
6
7
8
9
Shock Mach No. Ms.



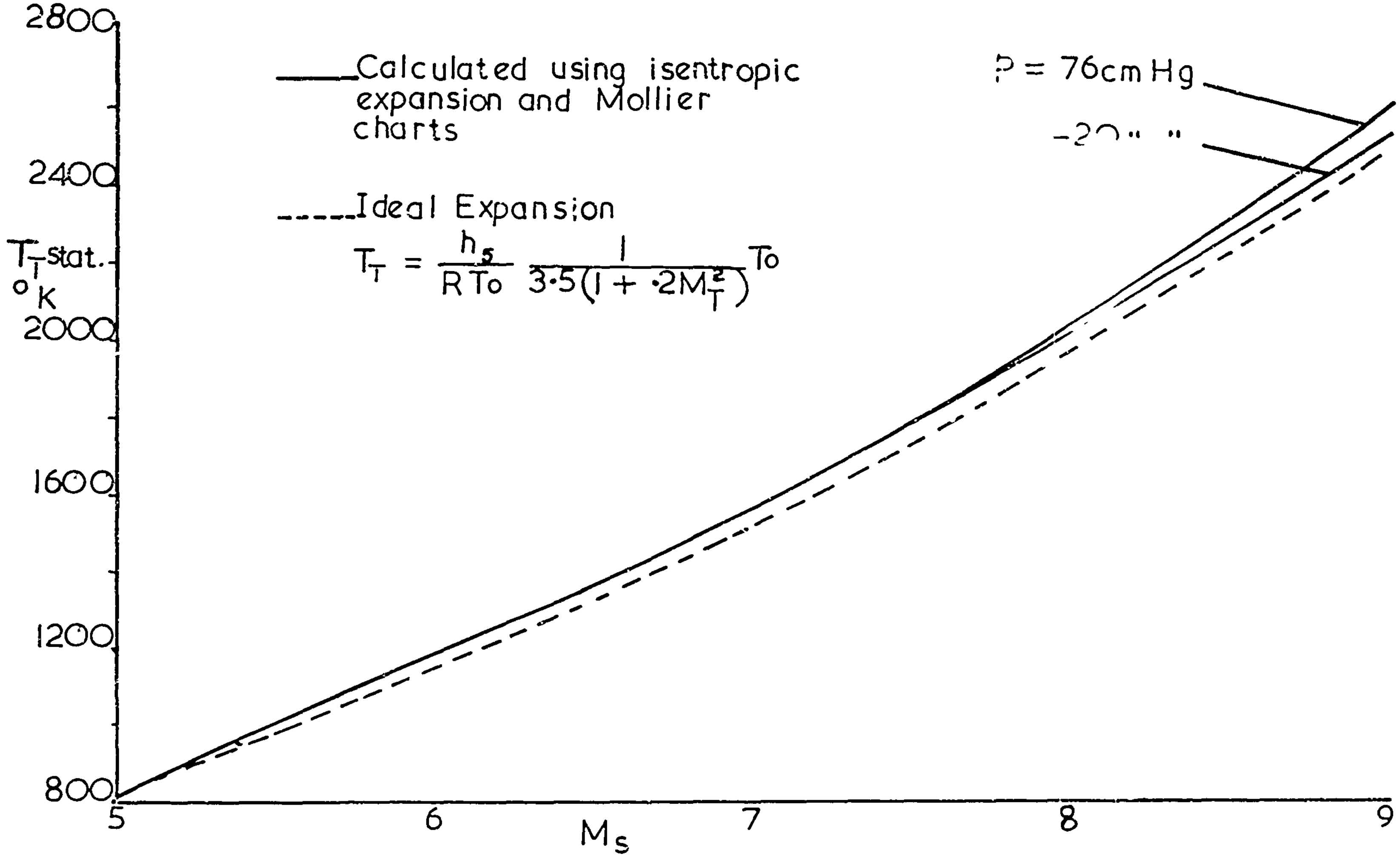
Test Section En
vs Primary Sh
Mach Number
Mach 3 Nozzle
P_1 = 1 cm Hg
20 " "
76 " "
180
160
140
120
100
80
60
Test Section Enthalpy
9
10
11
12
13
14
Shock Mach No. Ms.

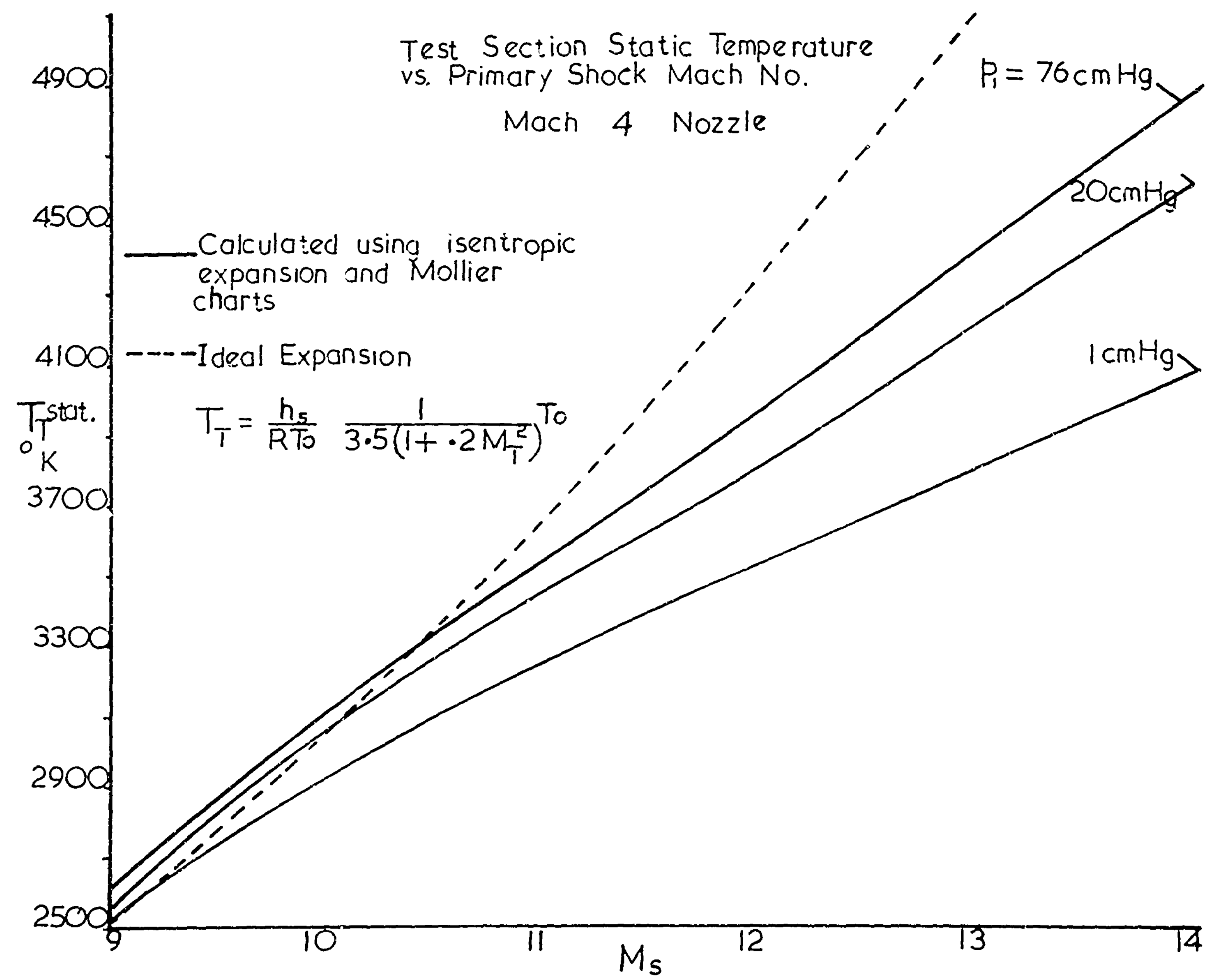

Test Section Static Pressure
vs. Shock Mach No.
Mach 4 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T stag}{P_T stat} = \left(1 + \cdot 2 M_T^2\right)^{3\cdot 5}$
P_1 = 76 cm Hg
P_1 = 20 cm Hg
P_T stat. psi.
M_s
0
10
20
30
40
50
60
5
6
7
8
9


Test Section Static Pressure
vs Primary Shock Mach No.
Mach 4 Nozzle
P_1 = 76 cm Hg.
P_1 = 20 cm Hg
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T \text{stag}}{P_T \text{stat}} = (1 + \cdot 2M_T^2)^{3\cdot 5}$
P_T stat. psi
130
110
90
70
50
30
10
9
10
11
12
13
14
M_s

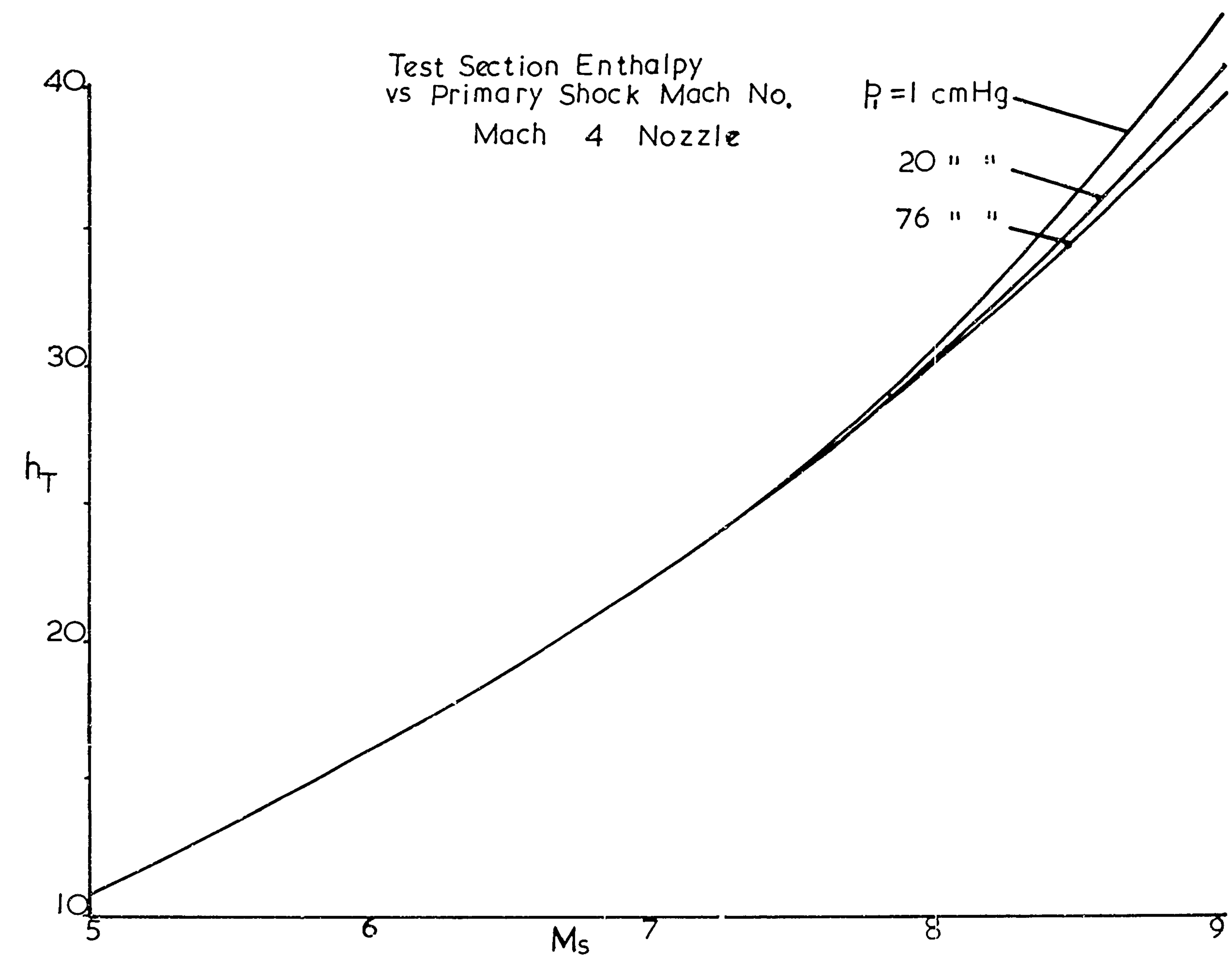

Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 4 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T stag}{P_T stat} = \left(1 + \cdot 2M_T^2\right)^{3\cdot5}$
$P_T stat$
psi
0
1
2
3
5
6
7
8
9
10
11
12
13
M_s

Test Section Static Temperature
vs Primary Shock Mach No.
Mach 4 Nozzle

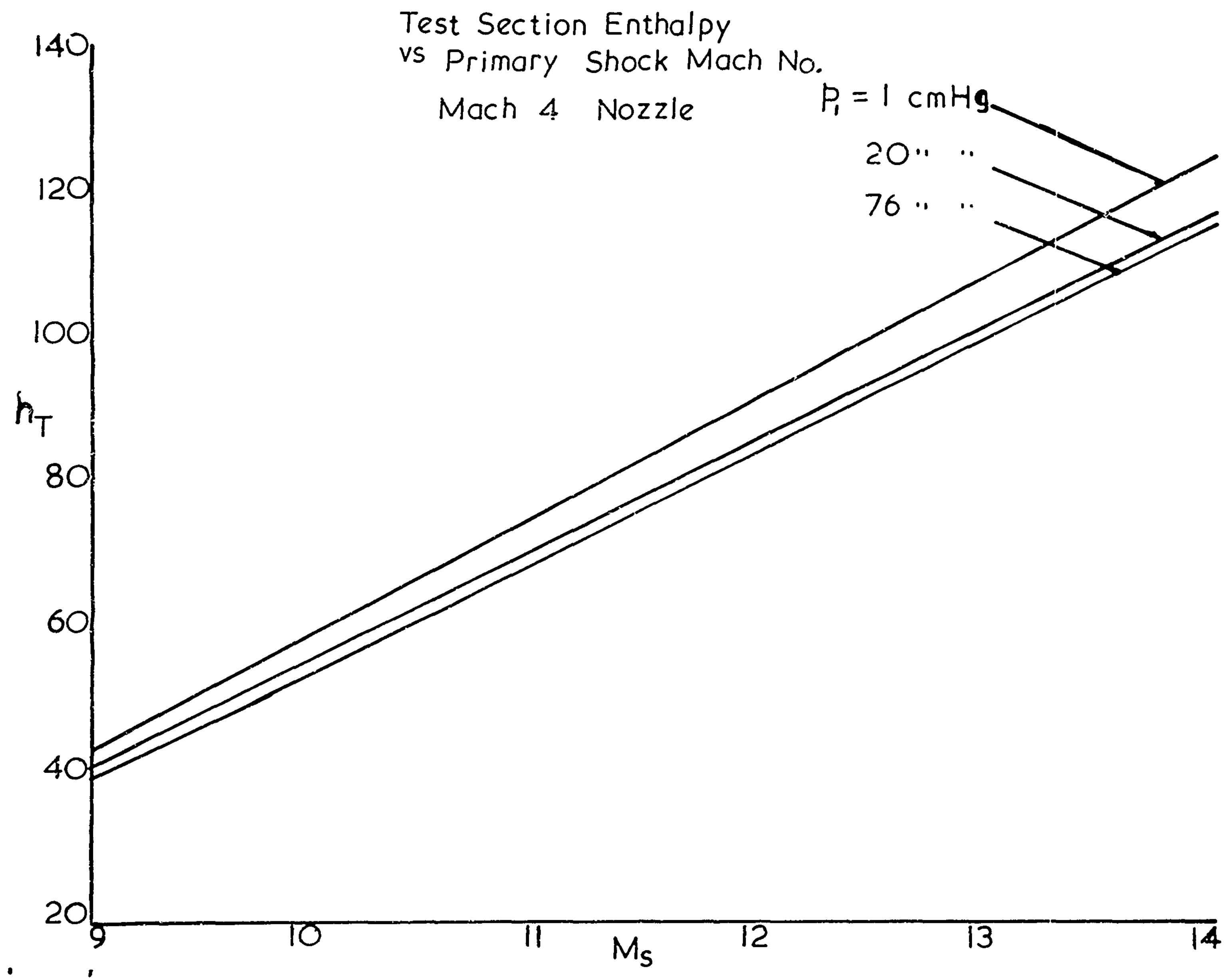




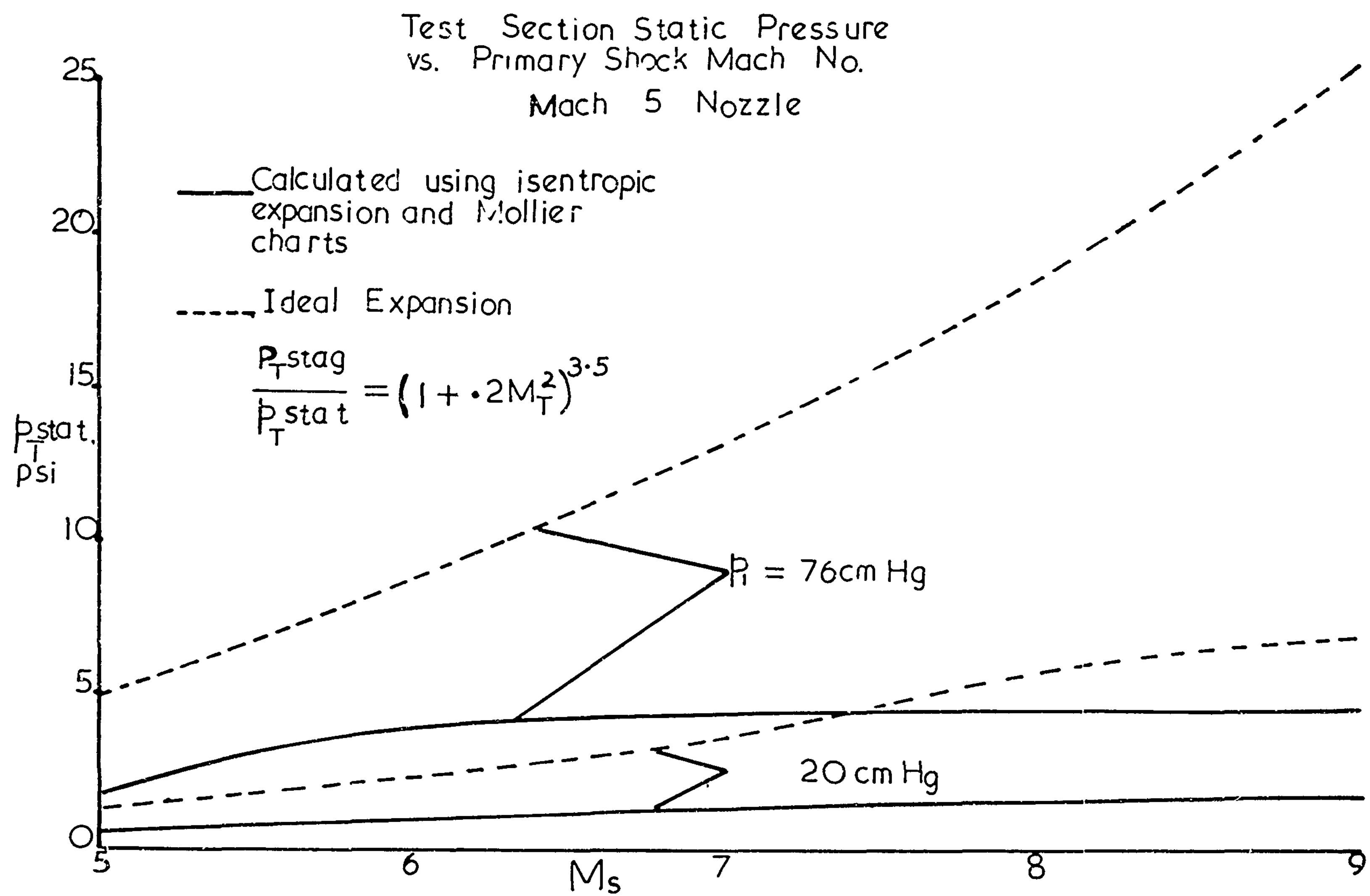
Test Section Static Temperature
vs. Primary Shock Mach No.
Mach 4 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{RT_0} \frac{1}{3.5(1+.2M_T^2)} T_0$
P_1 = 76 cmHg
20cmHg
1cmHg
$T_T^{stat.}$ °K
4900
4500
4100
3700
3300
2900
2500
9
10
11
12
13
14
M_s

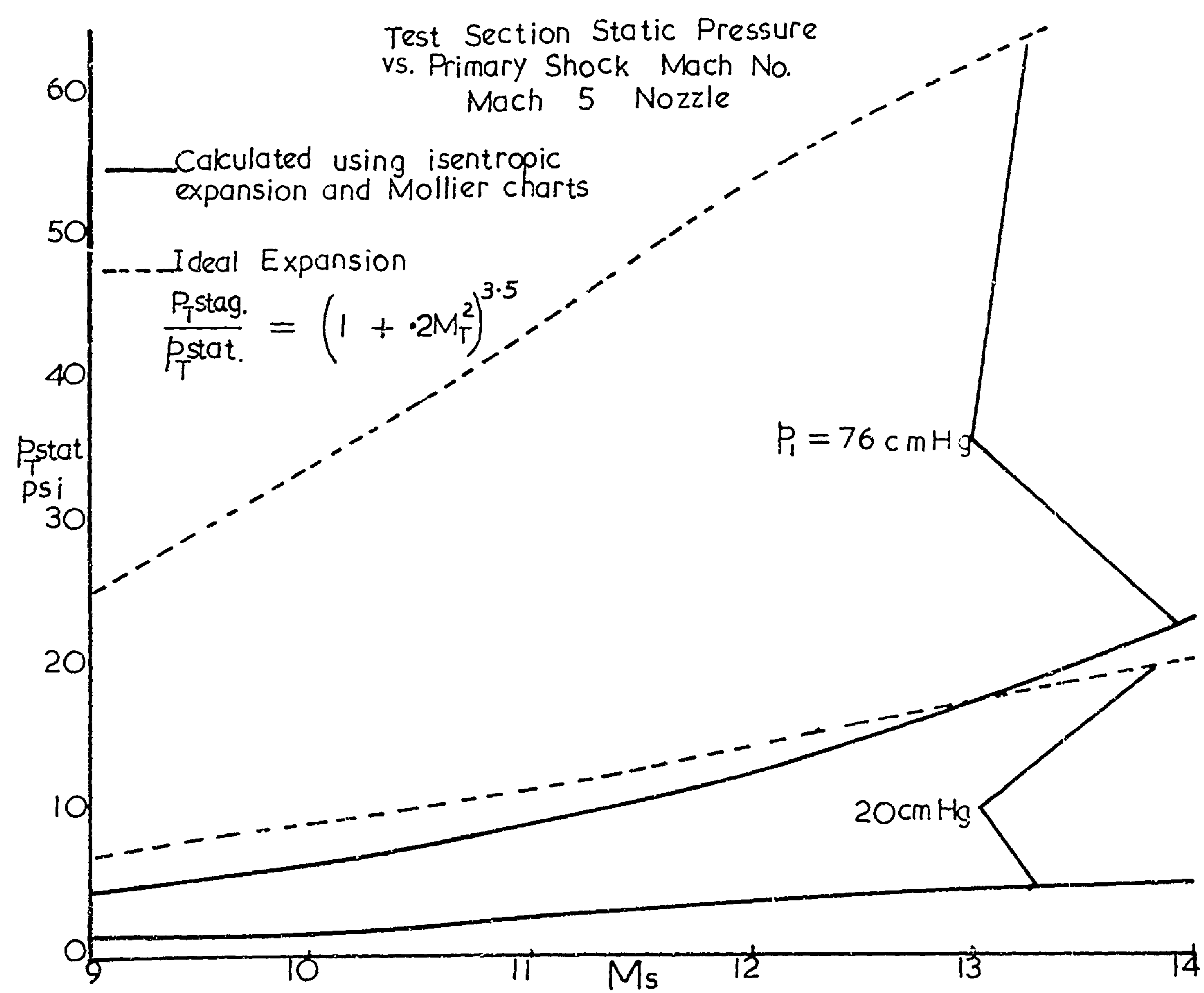


Test Section Enthalpy
vs Primary Shock Mach No.
Mach 4 Nozzle
p_1 = 1 cmHg
20 " "
76 " "
40
30
20
10
h_T
5
6
7
8
9
M_s

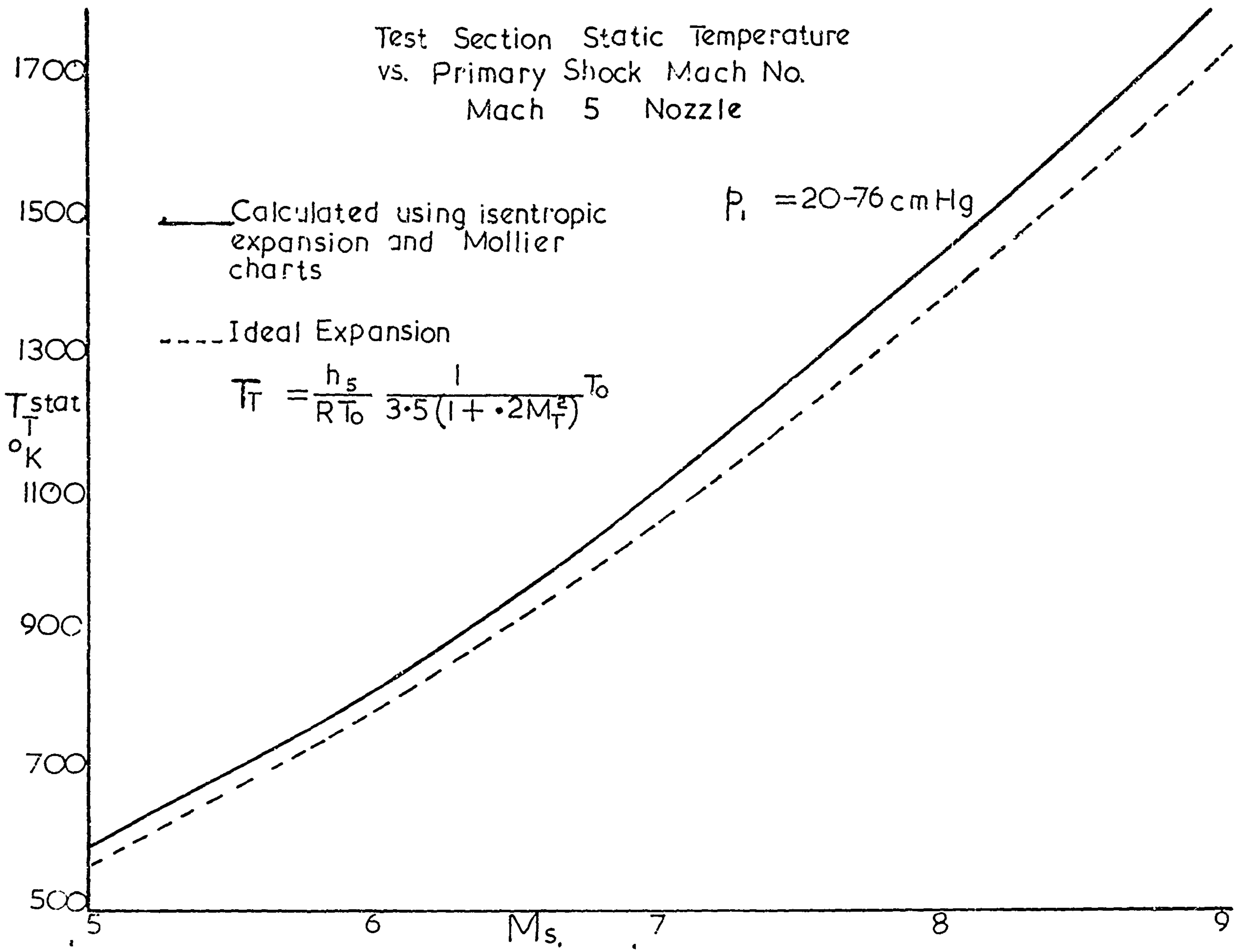


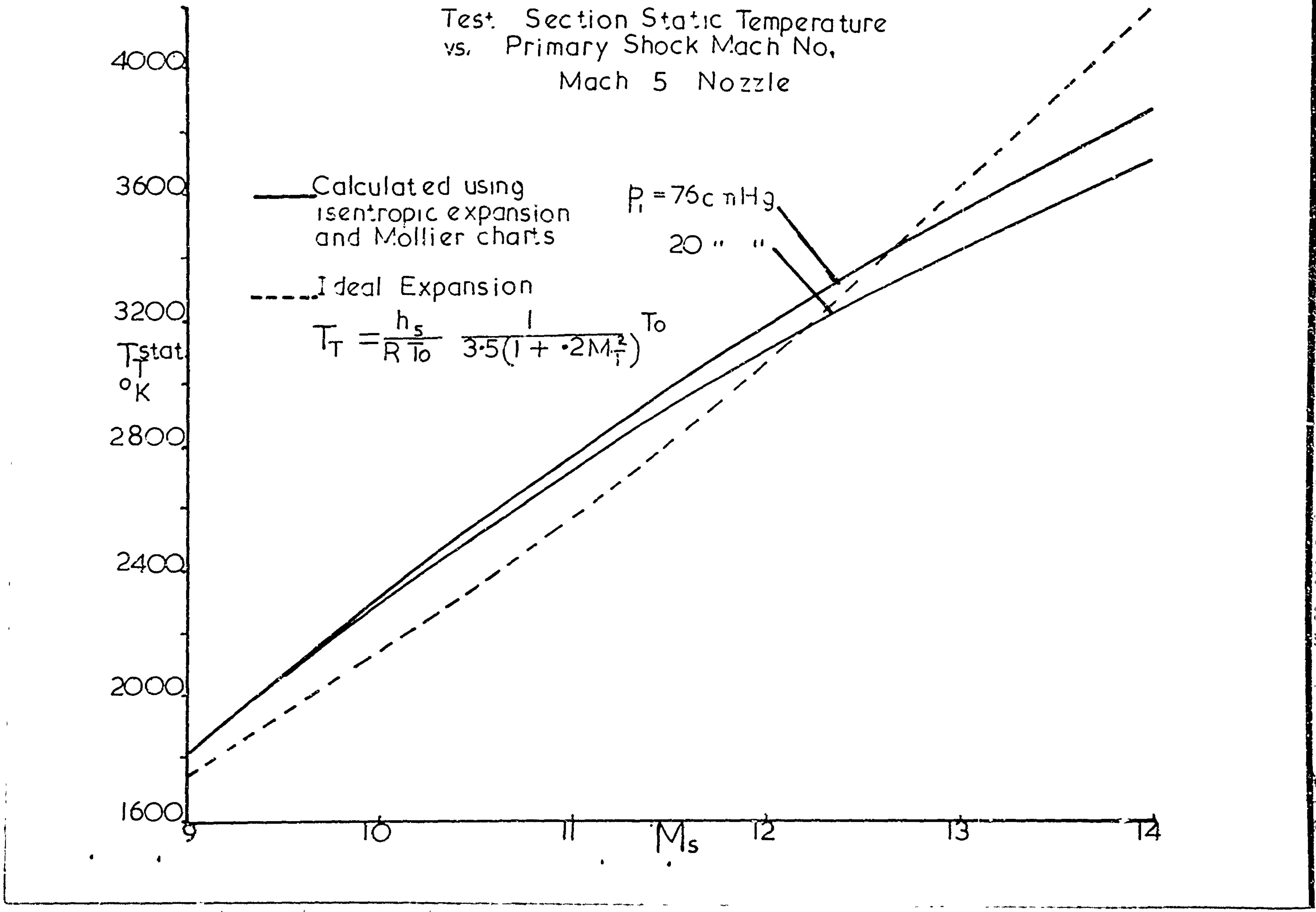
Test Section Enthalpy
vs Primary Shock Mach No.
Mach 4 Nozzle
p_1 = 1 cmHg
20 " "
76 " "
h_T
140
120
100
80
60
40
20
9
10
11
12
13
14
M_s


Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{p_T\,stag}{p_T\,stat} = (1 + .2M_T^2)^{3.5}$
p_T stat. psi
p_1 = 76cm Hg
20 cm Hg
M_s
0
5
10
15
20
25
5
6
7
8
9

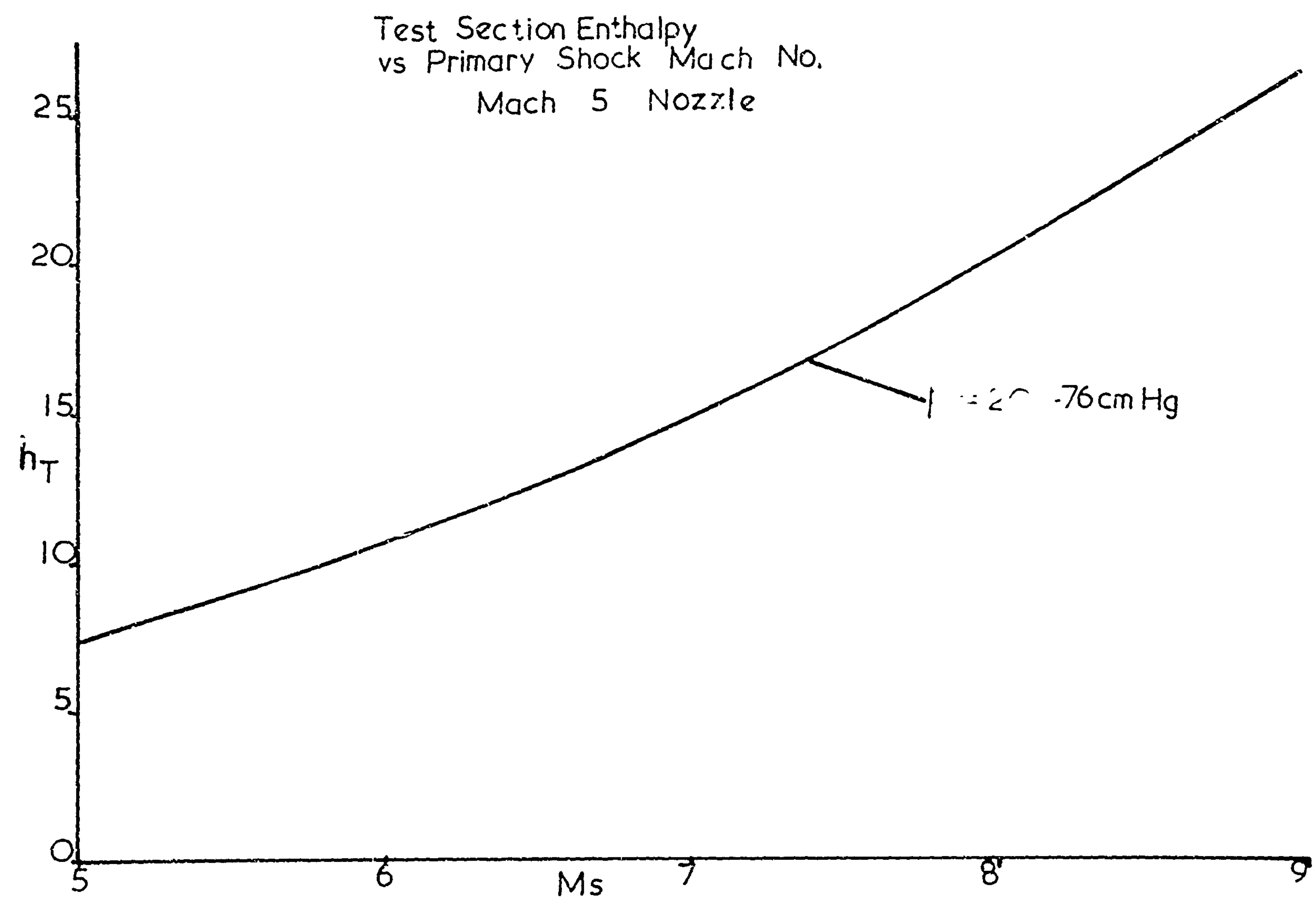


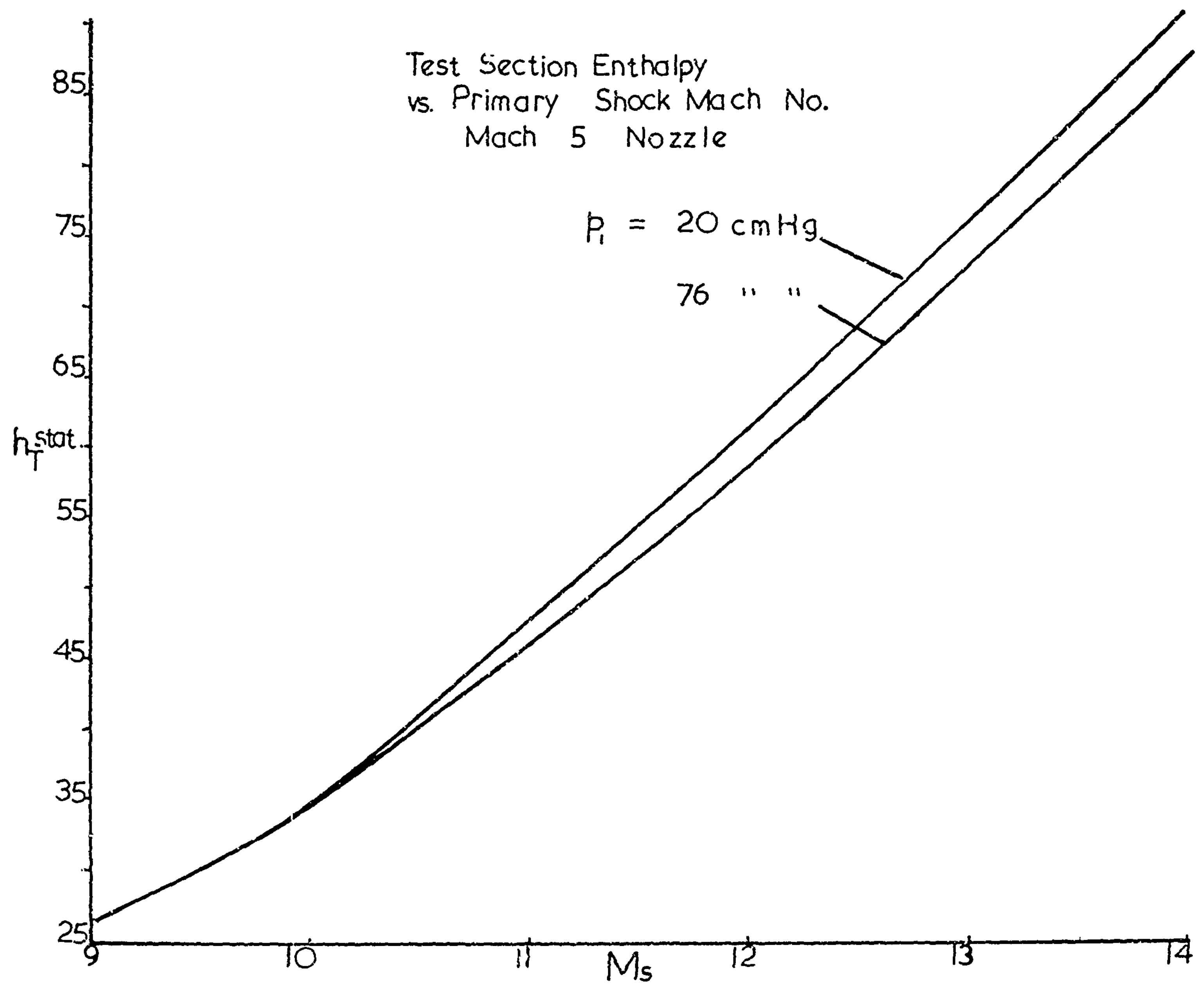
Test Section Static Pressure
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$\frac{P_T stag.}{P_T stat.} = \left(1 + \cdot 2M_T^2\right)^{3\cdot 5}$
$P_1 = 76$ cmHg
20cmHg
$P_T$stat psi
0
10
20
30
40
50
60
9
10
11
12
13
14
Ms


Test Section Static Temperature
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_5}{RT_0} \frac{1}{3{\cdot}5(1+{\cdot}2M_T^2)} T_0$
$p_1 = 20\text{–}76$ cm Hg
T_T^{stat} °K
1700
1500
1300
1100
900
700
500
5
6
7
8
9
M_s.



Test Section Static Temperature
vs. Primary Shock Mach No.
Mach 5 Nozzle
Calculated using isentropic expansion and Mollier charts
Ideal Expansion
$T_T = \frac{h_s}{R\,T_o} \frac{1}{3.5(1 + .2M_T^2)} T_o$
P_1 = 76cm Hg
20 " "
4000
3600
3200
2800
2400
2000
1600
T_T^{stat} °K
9
10
11
12
13
14
M_s


Test Section Enthalpy
vs Primary Shock Mach No.
Mach 5 Nozzle
25
20
15
10
5
0
h_T
5
6
7
8
9
Ms
-76cm Hg



Test Section Enthalpy
vs. Primary Shock Mach No.
Mach 5 Nozzle
p_1 = 20 cmHg
76 " "
85
75
65
$h_T^{stat.}$
55
45
35
25
9
10
11
12
13
14
M_s

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13. ABSTRACT

This report contains calculated conditions expected in the test section of the Sheffield University Shock Tunnel.

The driver gases used are either cold hydrogen or a mixture of hydrogen oxygen and helium ignited behind the primary diaphragm. Cold hydrogen "Tailors" at a primary shock March number of 6 and the helium mixture used at about 12. The report therefore deals with the primary shock Mach number ranges from 5 to 9 and from 9 to 14 to cover both these cases.

The air in the stagnation region is expanded to test section Mach numbers of 3,4 and 5 depending on the nozzle attached.

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Supersonic Combustion						
Hypersonic Shock Tunnel						
Hypersonic Flight						
SCRAMJET						